On Philosophy of Quantum Gravity

Jeremy Butterfield

Cambridge University

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Outline

Halfway through the woods

'Midway through the journey of our life, I found myself within a dark wood, for the right way had been lost.' (Dante, Inferno I)

Rovelli (1997) draws the analogy between the struggles from Copernicus to the Newtonian synthesis (1543—1687) and our own struggles (1900—??). He enjoins philosophers:
'... philosophical thinking [is] probably necessary to help physics out of a situation in which we have learned so much about the world, but no longer know what matter, time, space and causality are. As a physicist involved in this effort, I wish the philosophers who are interested in the scientific description of the world would not confine themselves to commenting and polishing the present fragmentary theories, but would take the risk of trying to look *ahead*' (1997, p.182).

The over-arching question: what should guide us in guessing what are the fundamental degrees of freedom of the reconciliation of relativity and quantum theory, of the quantum theory of gravity?

The *status quo*, described on a more detailed time-scale:—

a) The decade 1965-75 saw an explosion in physics, comparable to 1905-30.
b) And it saw an explosion (well, a bang ...) in philosophy.
c) Hence the development of the philosophy of physics since 1970: it is now in seamless contact with foundations of physics ...

This has been a great stimulus to natural philosophy. Examples:
i) quantum non-locality sheds light on philosophy of cause and probability
ii) quantum indistinguishability sheds light on philosophy of identity.

What use philosophy?

And of course, foundational issues are relevant in today's heuristics for finding tomorrow's fundamental physics. But what are the prospects for *philosophers* contributing to the quest for quantum gravity, today and tomorrow ?

What could be the role of philosophy, apart from
a) a scavenger picking over dead theories for its own purposes; or
b) a Greek chorus, or a camp follower; or at best
c) a minor symbiote, like a few pilot fish, which eat the ectoparasites on the skin of a great white shark—ancillary cosmetic, manicuring, services—and receive in return protection from predators ?

Philosophers are few; their conceptual armoury is small and out of date. (I set aside scholarly, e.g. historical, study: though invaluable, it contributes to the practice of quantum gravity only rarely—e.g. Julian Barbour.)

John Locke, in his 'Epistle to the Reader' in *An Essay Concerning Human Understanding*, sees his role as a 'minor symbiote'. In his words, as 'under-labourer':

The commonwealth of learning is not at this time without master-builders, whose mighty designs, in advancing the sciences, will leave lasting monuments to the admiration of posterity: but every one must not hope to be a Boyle or a Sydenham; and in an age that produces such masters as the great Huygenius and the incomparable Mr. Newton, with some others of that strain, it is ambition enough to be employed as an under-labourer in clearing the ground a little, and removing some of the rubbish that lies in the way to knowledge...'

More specifically, his role is to see through beguiling words:

... knowledge; which certainly had been very much more advanced in the world, if the endeavours of ingenious and industrious men had not been much cumbered with the learned but frivolous use of uncouth, affected, or unintelligible terms, introduced into the sciences, and there made an art of ...
Vague and insignificant forms of speech, and abuse of language, have so long passed for mysteries of science ... that it will not be easy to persuade either those who speak or those who hear them, that they are but the covers of ignorance, and hindrance of true knowledge. ...
Few are apt to think they are deceived in the use of words; or that the language of the sect they are of has any faults in it ...

So I will warn you about beguiling words ...

The vacuum properly understood
Nowadays, 'the vacuum' means: the system's ground-state.

Much popular physics is mystery-mongering: 'a hindrance of true knowledge'.
For it suggests that the vacuum is nothing, i.e. is the absence of the system—and yet is, mysteriously, "active", "full of fluctuations".
Cf. Albert's 2012 devastating *New York Times* review of Krauss' *A Universe from Nothing*.

Besides, when the theory takes space or spacetime as given, even without a physical system: it is yet more mystery-mongering to call the absence of the system 'nothing'.

The first point applies similarly to theories in which space or spacetime is part of the system, such as GR, LQG or causal sets.

That infernal cat again: 'first quantisation is a mystery'

In the reconciliation of relativity and the quantum, it might not be relativity that makes the most compromises. Maybe quantum theory has to mend its ways. Recall the scandal of the measurement problem; and our lacking a relativistic theory of measurement.

What is the physical meaning of a quantum superposition, i.e. complex amplitudes for different configurations? What does $|\psi\rangle \in L^2(\mathcal{Q})$ really represent?
Just because this question is familiar does not mean we can be blasé about it (except perhaps on a pilot-wave view).

All the more so when the configurations are something that seems more fixed and-or background and-or abstract than positions of bodies. Namely: geometries or topologies of space; more precisely, for LQG, assignments of values to discrete area and volume operators.

And our question is not answered just by being an Everettian . . .

Tu quoque Dr Everett...

For: today's clear-headed Everettian (living in Oxford!) says:
(Pattern): A macroscopic object is an appropriate *pattern* in the quantum state of the microscopic degrees of freedom.

So in non-relativistic wave mechanics: Consider a wave-function $|\psi\rangle$ on the classical configuration space $\mathcal{Q} := \mathbb{R}^{3N}$ of $N := 40 \times 6 \times 10^{24}$ point-particles. (So $q \in \mathcal{Q}$ represents each of 6×10^{24} atoms as comprising, on average 40, spinless particles.)

Suppose $|\psi\rangle$ is peaked over both
(i) a region of classical configurations representing a live cat (warm, walking, tail vertical); and
(ii) a region of classical configurations representing a dead cat (cold, lying down, tail horizontal).

$|\psi\rangle$ certainly represents two patterns. So by (Pattern), $|\psi\rangle$ represents two cats. So in such a world, there are two cats.

But such an Everettian should ask:
what is represented by a superposition of microscopic *degrees of freedom?*

Or even: *by an eigenstate of them?* E.g.: by a delta-function of position?

The textbooks (we all!) usually say: such a state (and similar ones, like coherent states of the microscopic degrees of freedom) is the quantum surrogate for a classical particle.

It seems wrong to combine (Pattern) with this. For it would mean endorsing, when interpreting our formalism for microscopic degrees of freedom, classical physical ideas that are construed by (Pattern) to be emergent/effective. (So this appeal to the classical is very different from those of Bohr and Copenhagen.)

But: Why should the microscopic degrees of freedom be understood in terms of what we believe is emergent and effective?

An analogy with condensed matter approaches to QG.
Recall that on these approaches, the traditional idea of quantizing the metric field in e.g. GR, as a way of guessing what is a quantum theory of gravity, looks very misguided.

For it would correspond, in the context of condensed matter, to trying to guess the microscopic quantum theory of the system by quantization of the classical effective equations, which will of course in general be very dependent on a regime of parameter values and maybe on specific states.

This returns us to the basic question: what should be our guide to the fundamental degrees of freedom of any putative quantum theory of gravity?

We can hardly expect these degrees of freedom to oblige us by obeying equations we happen to know from e.g. the microscopic theory of liquids. Agreed: talent and industry have already found suggestive cases.

Galileo: 'Nature is a book written in the language of mathematics.'

Accepting the distinction since 1850 between pure and applied mathematics, it would be better to say:
'Nature is a book written in the syntax of mathematics, but with the semantics of physics'.

That distinction yields our present predicament:

a) the problem of Platonism in the philosophy of mathematics: how to reconcile our knowing about abstract objects with empiricist epistemology?

b) Wigner's question: why is pure mathematics so effective in the empirical sciences?

My own views *seriatim* ...

Beware of Pythagoreanism—and Max Tegmark!

I surely know some pure mathematical propositions more firmly than the premises of any empiricist epistemological arguments that I cannot know them! But mending empiricist epistemology is work for another day ...

But I deny that everything is pure mathematical: I am not a Pythagorean.

Tegmark (*Our Mathematical Universe*) is a Pythagorean. His 'Mathematical Universe Hypothesis' (MUH) says:

MUH: Our external physical reality is a mathematical structure.

He thinks this follows from a realist premise, the 'External Reality Hypothesis' (ERH), which almost everyone believes:

ERH: There is an external reality completely independent of humans.

I am a realist and endorse (ERH). And I would allow that:
(ERH) implies that physical reality has an utterly objective description; and that:
This implies that physical reality instantiates a pure mathematical structure.

But this does *not* imply MUH. Instantiating a pure mathematical structure does not imply *being* one. The 'is' of identity, e.g. in 'a = b', is not the 'is' of instantiation, e.g. in 'Max is tall'.

Indeed, our modern view is: a physical structure involves physical quantities; a pure mathematical structure does not.

This is perfectly compatible with a physical structure being an instance of a pure mathematical structure. But it is incompatible with them being identical—however we choose to make precise 'physical quantity' (or similar notions like 'physical content').

Wigner's question

I have a Pedestrian Response, and an Excited Response. (Being a Pythagorean would not help either of them.)

The *Pedestrian Response*: Mathematics is the deductively organized science of patterns. Empirical enquiry seeks patterns in Nature, and seeks to articulate their relations. So of course, it turns to mathematics.

(i) A pattern is: abstract, general, classifying. It abstracts from detail, i.e. it is common to several instances; and so instances are classified by it.

(ii) Deductive organizing what we believe about patterns yields relations, such as implication, between patterns; and so between classifications.

Features (i) and (ii) are both endemic in modern mathematics.

A summary of the Pedestrian Response to Wigner's question:

We forget how much of even the purest mathematics has its roots in physical sources and how many structural similarities hold between diverse physical situations;
we forget how many phenomena can't be described in mathematical terms and how much pure mathematics has no application;
we forget what a wide range of pure mathematics there is to choose from in our efforts to describe the world; and
we don't take into account the widespread fudging that is involved in successful applications.

(P. Maddy, *Second Philosophy* (Oxford U.P., 2007), p. 343)

The *Excited Response*: The various deep unities in the physical world are pieces of good fortune that 'we neither deserve nor understand'. (Similarly, our ability to discover physics: if it was always cloudy, would we have ever solved the two-body problem—or done mechanics?)

The physical world is very unified:
historically: laws found on Earth are accurate for phenomena long ago
geographically: . . . and for phenomena light-years away
materially: our bodies are stardust
conceptually: physics deals with so few quantities, and so few constants; its diverse laws share symmetries, and follow from similar action principles...

Physics itself explains many of these unities. But a feeling of awe remains ... Are some of these pieces of good fortune a hint of some kind about quantum gravity?

A puzzling scenario about truth:
Does reality admit two or more complete descriptions which
(Different): are not notational variants of each other; and yet
(Success): are equally and wholly successful by all epistemic criteria one should impose?

If so, should we say: thanks to (Success), both descriptions are true, in a correspondence sense of 'true'; yet, thanks to (Different), they are 'incommensurable'? So reality is 'amorphous'.

Or should we say that (thanks to (Different)) at most one of the descriptions is true, yet (thanks to (Success)) we cannot tell which of them is true? Jargon: 'under-determination of theory by data'.

Could dualities in physics give examples? Of either the first verdict, or the second?

A duality is, roughly, an 'isomorphism' D between two theories, or from a theory to itself: an 'isomorphism' of the state-space, collection of quantities, and associated descriptive apparatus e.g. bases and charts. A duality can be very useful to solve problems, and as a heuristic for guessing another theory. But here, I ask only whether dualities give examples of such pairs of descriptions.

Usually, it is clear whether (a) D changes the physical state, and the values of quantities; or (b) D changes only associated descriptive apparatus. So the philosophical situation is also clear: we do *not* face the puzzling scenario.
In case (a), condition (Success) fails: the two descriptions are not equally and wholly successful.
In case (b), condition (Different) fails: the two descriptions are notational variants of each other.

But: Is the situation also clear, as regards string dualities, like T-duality or gauge/gravity?

Example of D changing the state, but not the descriptive apparatus:
The harmonic oscillator, with $H = \frac{p^2}{2m} + \frac{1}{2}m\omega^2 x^2$. Define D on the (x, p) plane by

$$D : x \mapsto \frac{p}{m\omega} \;\; ; \;\; p \mapsto -m\omega x \; . \qquad (1)$$

Then $D(H) = H$, i.e. D preserves the ellipses of equal energy in the (x, p) plane: D combines a clockwise rotation by $\frac{\pi}{2}$ with a re-scaling (viz. dilation by $m\omega$ and contraction by $\frac{1}{m\omega}$).

But there is no temptation to identify a state $\langle x, p \rangle$ and its image $D(\langle x, p \rangle)$. If describing *this* harmonic oscillator as in $\langle x, p \rangle$ at time t_0 is accurate, then describing it as in $D(\langle x, p \rangle)$ is plain wrong.

That is: the second description is not empirically successful. (Agreed: (1) in this example there is one theory (self-duality); but there are two descriptions; (2) don't get confused by also changing your language!)

In some other examples, D changes the system, albeit to a replica system, as well as the state: e.g. Kramers-Wannier duality.

Examples of D changing the descriptive apparatus, but not the state:

Let D be change of basis in a vector space: for example, the unitary transformation (Fourier transform) between the position and momentum representations in elementary quantum mechanics ('wave-particle duality').

Or let D be a change of coordinate system in differential geometry/classical field theory.

In both examples, D connects two descriptions of any given state. One description may be vastly more useful for solving a problem. But they are notational variants of each other. So again, we do not face the puzzling scenario.

In both T-duality and gauge/gravity duality, the two descriptions differ about space-time structure. And we *seem* to face the puzzling scenario ...

In T-duality, the two dual descriptions each describe a compact spatial dimension. But one says it has radius R, the other says it has radius $1/R$. So condition (Different) seems satisfied: the two descriptions are not notational variants.
But they also differ about matter fields etc., in just such a way that no observation of any quantity could give evidence for one of the radii rather than the other. So condition (Success) seems satisfied.

Similarly for gauge/gravity duality. But here the alternatives about space-time structure are, not the size of a compact spatial dimension, but the number of spacetime dimensions.
The differing dimensions (and other disparities in the 'dictionary'!) suggest the two descriptions are not notational variants. But it seems no observation of any quantity could distinguish them.

Philosophers and physicists tend to differ in their reactions to such pairs of descriptions. Philosophers tend to favour our second verdict, that at most one of the descriptions is true. Physicists tend to favour our first verdict, that both descriptions are true.

That is: Philosophers allow that there are two alternative ways the world could be; or in some cases, in a single possible world, there are two 'regimes/sectors of reality' each described by one alternative.
In short, the descriptions are not equivalent; and either of them could be true.
But they would be true in different worlds or in different regimes in a given world.

Physicists tend to construe the descriptions as notational variants, describing a single possible world (or a single regime within a world).

Why the difference? Is it just that philosophers have come to reject verificationism, while it lingers among physicists? Maybe. But also:

Philosophers emphasize interpretation, irrespective of heuristics. So, unmoved by verificationism, and used to sceptical scenarios:–
they tend to distinguish possibilities.

But physicists recall several historical cases in which such a pair of apparently distinct theories was a prelude to an advance, i.e. to a formulation of a new theory that elided the apparent difference, and was agreed to be an improvement.

E.g. the formulation of Galilean spacetime, and its elision of different identifications of absolute rest.
E.g. the formulation of generally covariant GR, and its elision of different identifications of which spacetime point is which (the hole argument).

So I think physicists' rationale for denying that there are two theories is, in part, that in previous cases, eliding the apparent difference was agreed to be an improvement. In short: *'Replicas today suggest Ockham tomorrow.'*

BUT: Do we really face the puzzling scenario? Do the differing radii (or differing dimensions) really imply that the two descriptions are not notational variants (the scenario's condition (Different))?

Maybe the differences in radii/dimensions are "gauge", and will drop out of sight with a better formulation of string theory. Compare the familiar idea that the set of quantities does not separate the set of states...

If indeed we face the puzzling scenario, then—if the theory concerned is true—there is no fact of the matter about what is the radius of the compact dimension, or what is the number of dimensions, of physical spacetime. An amazing conclusion!